Crewed and Space Transportation Systems Cost Model

CASTS

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OUTLINE

- **CASTS – Where it is today**
    - Model Development Process
    - Historical Database
    - Estimating Approach
        - Example
    - Results/Observations
- **NEXT STEPS – Work in process**
    - Virtual Black Books
    - Functional Breakdown Structure
    - CER Updates
    - Full Life Cycle Cost Capability

Overall Goals

- **Philosophical framework**
  - Develop a new, unique cost model for use in estimating space transportation systems, including crewed systems, and earth-to-orbit and in-space transportation systems.
  - Based on historical database consisting exclusively of transportation/crew systems
  - *Credible*, *Supportable*, *Defendable* estimates
- **Initial Emphasis: Basis of Estimate**
  - Traceability and transparency of estimate to database
    - Development and documentation of the database and analytical processes behind the CERs incorporated in the model
    - Provide flexibility to use CASTS data/model as point-of-departure for tailored/customized estimates

Crewed and Space Transportation Systems Cost Model

Model Development Process

- **CASTS development process**

NAFCOM Source Data

Other Source Data

Work Breakdown Structure

Data Analysis Process

Analyzed Historical Database

Develop CERs

Incorporate in PCEC

- **Calculated “adjustment factor” for each data point**
  - Value which results in data point cost value when regression equation applied to data point independent variable(s)
  - Nominal value = 1.0; simple weight/other-based CER
  - Not a “complexity” factor – says nothing about why value is what it is

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Historical Database

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- **Reconstituting Historical Database has been primary focus to date**
  - NAFCOM heritage: trace back to source documents
  - New systems: Develop suitability for inclusion in database
  - *DOCUMENTATION* – from sources to CERs
    - Analysis spreadsheets, references

Roster of systems currently included in CASTS CER datasets

Launch Vehicles
Atlas V Common Core Booster
Atlas V Centaur
Apollo Command/Service Module
Apollo Lunar Module
Centaur D
Centaur G' (Shuttle Centaur)
Centaur G' CISS - ASE
Shuttle External Tank
Shuttle Orbiter
Shuttle Solid Rocket Motor
Shuttle Solid Rocket Booster
Saturn V 1st Stage (SIC)
Saturn V 2nd Stage (SII)
Saturn V 3rd Stage (SIVB)
Titan Centaur
Titan IV 5m Fairing
Atlas I, II, IIA, IIAS
Super Lightweight External Tank

Liquid Engines
F1
J2
J2X
RS27
RD180
RL10
RS68
SSME

Solids
Titan IV SRMU
Athena Castor 120
Trident D5
Shuttle RSRM
Atlas IIAS Castor 4A
Atlas V SRM
Ariane V EAP-P230
Pegasus

Software
SSME Adv Health Mgt Sys
Orbiter Cockpit Avionics Upgrade
Orbiter Primary Avionics Software Sys
Orbiter Backup Flight Software
BRAHMS
DART
X33
Centaur G'
Atlas II
Atlas V

KAR

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Work Breakdown Structure

- **CASTS - Work Breakdown Structure**

Program Segment		
	Program Mgt & Support	
	Systems Engr & Integ	
Vehicle Segment		
	Integration, Ass'y, Checkout	
	Crew Structures	
		Wing
		Tail
		Fuselage/Body
		Capsule Structures
	Thrust Structure	
	Adapters	
	Secondary/Support Structs	
	Tanks	
	Intertank	

Vehicle Segment (cont'd)		
	Mechanisms	
		Thrust Vector/Flight Control
		Separation
		Recovery
		Other
	Main Propulsion Systems	
	Thermal Protection	
		Passive
		Re-Entry Leading Edges
		Re-Entry Heat Shield
	Propulsion	
		Liquid Engines
		Solid Motors
		Reaction Ctl/Orb Maneuv Sys

Vehicle Segment (cont'd)		
	Avionics & Power	
		Guidance, Nav, & Control
		Telemetry & Tracking
		Command, Ctl, Data Handling
		Range Safety/Flt Termination
	Electric Power	
	Shroud/Fairing	
	Crew Systems	
		Environ Ctl & Life Supt
		Displays/Controls
Software Segment		
	Flight Software	
	Ground Software	
Test Segment		
	System Test Operations	
	System Test Hardware	
Ground Segment		
		Ground/Test Support Equip
		Tooling

Crewed and Space Transportation Systems Cost Model

CERs by WBS Element

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- **Work Breakdown Structure – Cost Estimating Relationships**

Program Segment		
	Program Mgt & Support	
	Systems Engr & Integ	
Vehicle Segment		
	Integration, Ass'y, Checkout	
	Crew Structures	
		Wing
		Tail
		Fuselage/Body
		Capsule Structures
	Thrust Structure	
	Adapters	
	Secondary/Support Structs	
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Vehicle Segment (cont'd)		
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	Flight Software	
	Ground Software	
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	System Test Operations	
	System Test Hardware	
Ground Segment		
		Ground/Test Support Equip
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CER Type
Cost-to-Cost
Des & Dev + Flt Unit (wt/other)
Adjustment Factor
Multi Var CER (DD & FU)

Estimating Approach

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- **Why this approach?**
  - Significant data “clutter”
    - Minimal number data points with multiple potential variables
    - Lack of/dissimilar definitions between sources
    - Poor predictive value (P-values >> .05)
    - Counter intuitive results (cost > over time, cost < increased complexity)
  - Conflicting/countervailing influences between potential variables
    - Time vs. degree of new design vs. technology level vs. SOA vs. etc.
  - Calculated “adjustment factor” for each data point
    - Not a “complexity” factor – says nothing about why value is what it is
  - Not the “final answer” (see Next Steps)

Example CASTS CER

- **CASTS CER Inputs/Process/Outputs Example – Thrust Structure**

  - Inputs: 30,000 lbs, in-line, multiple engines, Al 2219, extensive test program ("man-rateable"), constant 2015 $ (mil), 20 production units at rate of 4 per year, fabricated in-house by prime contractor (e.g. MAF)
  - Process:
    1. Thrust Structure CER
       - D&D$ = .1160 x wt^.6693 x adjustment factor
       - FU$ = .0079 x wt^.8121 x adjustment factor
    - Large (SIC = 55Klb, SII = 7Klb, ET = n/a), in-line, new design, multiple engines
       - Use SIC DD (1.1271) and FU (.7795) adjustment factors

Subsystem Adjustment Factors

Include?	Subsystem	Sub-Group	Mission	WBS Item	D&D Factor	Flt Unit Factor
	Thrust Structure		SIVB	Thrust Structure	1.48	1.34
x	Thrust Structure		SIC	Thrust Structure	1.13	0.78
	Thrust Structure		SII	thrust struct	1.09	1.57
	Thrust Structure		AV CCB	Aft Transition	0.62	0.76
	Thrust Structure		C-D	Thrust	0.90	0.80

Example CASTS CER

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- **CASTS CER Inputs/Process/Outputs**

2. System Test Hardware
   - Use CER (vs. standard 1.30 factor) = 2.313 x FU$^.9679
3. For Production Cost - assume 90% Crawford learning curve (typical); 65% rate curve (ET ≈ 60%)

- Outputs:

Estimate Summary

	DDT&E	Design & Development	System Test Hardware	Flight Unit	Production	TOTAL
FY2015 $M	$ 185.90	$ 129.86	$ 56.04	$ 26.92	$ 164.98	$ 350.89

D&D = $129.9 = .1160 x 30,000^.6693 x 1.127

FU = $26.9 = .0079 x 30,000^.8121 x .7795

STH = $56.0 = 2.313 x 26.9^.9679 x 1.000

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Example CASTS CER

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- **CASTS CER Inputs/Process/Outputs**
  - Outputs (cont'd):

Estimate Summary

	DDT&E	Design & Development	System Test Hardware	Flight Unit	Production	TOTAL
FY2015 $M	$ 185.90	$ 129.86	$ 56.04	$ 26.92	$ 164.98	$ 350.89

Production Cost Calculation FY2015 $M

Yr. No.	Cumulative Units	Learning Curve Effects	Production Quantity/Year	Recurring Production Cost/Year	Fixed/Variable Production Estimate/Year	Diff: RC vs. F/V
1	4	$ 95.28	4	$ 40.25	$ 31.78	1.267
2	8	$ 80.62	4	$ 34.06	$ 31.78	1.072
3	12	$ 74.81	4	$ 31.61	$ 31.78	0.995
4	16	$ 71.20	4	$ 30.08	$ 31.78	0.947
5	20	$ 68.59	4	$ 28.98	$ 31.78	0.912
6	20	$ -	0	$ -	$ -	0.000
7	20	$ -	0	$ -	$ -	0.000
8	20	$ -	0	$ -	$ -	0.000
9	20	$ -	0	$ -	$ -	0.000
10	20	$ -	0	$ -	$ -	0.000
TOTAL			20	$ 165.0	$ 158.9	

Average Cost per Unit
$ 8.249

Fixed/Variable Calculation

	FY2015 $M
T1,1	$ 30.79
Variable Cost per Unit	$ 2.42
Fixed Cost per Year	$ 22.10
Cumulative Diff	*$ (6.11)*
% Diff	*-3.7%*

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Example CASTS CER

- **CASTS Example Analyses**
  - <u>Sensitivity Analyses:</u>
    - Questions: How does unit and total production cost change if…
      1. We fly 1 more flight per year? 2?
      2. We fly 20 flights in 7 years? 28?
    - Process:
      - Change total production units and flights/year
    - Answers:
      1. +$9M Total, -$1.3M AUC; +$17M Total, -$2.2M AUC
      2. +$37M Total, +$1.8M AUC; +$55M Total, -$1.4M AUC

Years Ops:	5		
Rate Curve:	65%		
Flts/Year	4	5	6
Total Flights	20	25	30
Total Prod $	**$ 165.0**	**$ 174.1**	**$ 181.9**
Avg Unit $	**$ 8.25**	**$ 6.96**	**$ 6.06**
Var CPF	$ 2.42	$ 2.35	$ 2.29
Fixed CPY	$ 22.10	$ 21.44	$ 20.90

Years Ops:	7	
Rate Curve:	65%	
Flts/Year	3	4
Total Flights	20	28
Total Prod $	**$ 202.2**	**$ 220.5**
Avg Unit $	**$ 10.11**	**$ 7.88**
Var CPF	$ 2.48	$ 2.31
Fixed CPY	$ 22.65	$ 21.10

Results/Observations

- **Initial results**
  - Ran SLS Core stage through PCEC using CASTS CERs
    - Did not use any adjustment factors – all = 1.0
    - Result was less than 5% different than PRICE-based estimate
      - At top level; comparison at lower levels still to-do
- **Observations relative to CASTS development effort to date**
  - Data
    - Each point is important – need to understand each one as much as possible – drive back to source documentation
    - Significant amount of data clutter between sources
      - Different/inconsistent definitions, accounting methods, etc.
  - Independent Variables
    - Each datapoint is unique mix of potential independent variables
      - Time, complexity, inheritance, system evolution, SOA, materials, processes, configuration/definition, etc.

Crewed and Space Transportation Systems Cost Model

Next Steps – Work In Process

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- **Virtual Black Books**
  - CADRE-like – not a CADRE, but same type of information
    - Will be available online through REDSTAR

REDSTAR
Space Transportation System Data Collection (tag)

Click on

Launch Systems

- Atlas I, II, IIA, IIAS, V
- Saturn S1C
- Saturn SII
- Saturn IVB
- Shuttle Orbiter
- Shuttle External Tank
- Etc.
- Etc.

Users Guide

For each system element:
1. Resume = a Word file with summary description + source data references + explanation of derivation of cost data for CERs
2. Cost Analysis Spreadsheet = an EXCEL file with the calculations/derivations to get from source data to CER inputs
3. REDSTAR bibliography = scanned source documents (and non-scanned source data references)

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CASTS – Next Steps

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- **Functional Breakdown Structure**
  - Cost delineated by functions (Engineering, Touch, Manufacturing Support, Quality Assurance, etc.) rather than end items (weight, thrust, lines of code, etc.)
  - Much historical data is in this format; not always by end item
  - Many (most?) cost reduction/affordability approaches relate most directly to functions, not end items
    - E.g. Touch labor vs. automated welding; SR&QA vs. reduction in Gov't Mandated Inspection Points (GMIPS); Facility O&M vs. shared facilities
  - Schedule tasks usually address functions directly, not end items
    - E.g. "design", "analyze", "test", "fabricate", "inspect", etc.
  - FBS capability will allow more visibility/flexibility regarding estimates of (for instance):
    - Potential cost/savings of affordability initiatives
    - Integration of parametric-based estimates with JCL schedules

CASTS – Next Steps

- **CER Updates**
  - Expand historical database/incorporate in CERs
  - Explore meaningful independent variables
    - Replace Adjustment Factors
  - Investigate development of objective Complexity Generators
- **Full Life Cycle Cost Capability**
  - Time dimension - Full life cycle cost estimating capability: "sand charts"
    - Spread vs. non-spread cost
    - Cost as function of flight/production rates over time
    - (Capability) Nonrecurring facilities, mission and launch ops

Crewed and Space Transportation Systems Cost Model

CASTS – Summary

- **Model and data: Traceability and transparency**
  - Substantial progress made in reviewing, updating, and understanding the crewed and space transportation systems' historical database.
  - Documentation of the historical database provides a detailed but easy-to-use resource for NASA cost analysts to better understand the database itself and, as a result, provides a better basis of estimate for future estimates.
- **Estimating capability: Depth and breadth**
  - The initial set of CASTS CERs released with PCEC ver. 2.0, when coupled with the accompanying documentation, provide a set of estimating alternatives that cover the breadth of end items that comprise crewed and space transportation systems and a depth of understanding of the historical database upon which the estimate is based.

Credible, Supportable, Defendable